Novel Acoustic Techniques for Assessing Fish Schooling in the Context of an Operational Ocean Observatory

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LONG-TERM GOALS

Fish aggregation is important in terms of biology, fisheries, and measurement, quantitative analyses of gregarious movement behaviors remain relatively rare (Turchin 1989). Fish aggregation has most often been studied in easily accessed fish or fish easily maintained in the laboratory such as minnows and dace (see a review in Pitcher and Parrish 1993). Measurements of fish aggregations are often difficult, particularly in pelagic environments. Our goal is to develop new acoustic techniques that have the potential to serve as measurement tools to quantify this ubiquitous and important behavior.

OBJECTIVES

This project brings together a team with expertise in acoustics, engineering, biology, fisheries, and oceanography to develop and apply acoustic techniques to measure schooling in pelagic fish. We combined traditional, split-beam fisheries echosounding techniques and direct sampling with new acoustic techniques and new platforms in a study area monitored by an existing operational ocean observatory. To measure synoptic distributions of fish schools we collected mid-frequency back- and bistatic-scattering from fish using a unique horizontally oriented multibeam system. We will experimentally evaluate the use of ship-board and moored mid-frequency sonar for the detection and resolution of fish schools at long range (kilometer scale) in the context of propagation and scattering in a shallow water waveguide. Toward the goal of integrating mid to geometric frequency scattering measurements, we will observe the relationship of high frequency echosounder and multibeam measurements to mid-frequency short-range measurements (direct path scattering) and mid-frequency long-range measurements (waveguide scattering). In doing so, we will correlate the results of the longer-range measurement (less understood and more complex scattering geometries) with more traditional (better understood) higher frequency and geometric scattering regimes and techniques. We will also investigate the ability of higher frequency multibeam techniques to assess the internal structure of detected schools. A 200 kHz multibeam capable of collecting water column data will be integrated into an autonomous underwater vehicle (REMUS). Deploying this cutting edge instrument on an autonomous platform will allow us to access fish at greater depths, while sampling the high spatial resolution necessary to measure the geometry of fish in an aggregation. All field sampling will be conducted within the New Jersey Shelf Observing System (NJ SOS), which provides real-time data throughout the Mid-Atlantic Bight (MAB). The surveys will be positioned adaptively using real-time data collected with the international constellation of ocean color satellites, a nested grid of HF radars, and an operational fleet of autonomous Webb Gliders. The goal is to use the environmental data to

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14. ABSTRACT
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optimize ship and AUV acoustic surveys by using the observatory to identify specific water masses, frontal boundaries, and subsurface phytoplankton plumes. The surveys will then identify and track schools of fish associated with this hydrographic and biological structure. This approach will provide a context for the fish schooling information, allowing us to begin to look for correlations between the fish biology and environmental variability.

APPROACH

- *Develop new acoustic techniques to measure aggregations of fish*
  - High-frequency multibeam sonar on autonomous underwater vehicle (AUV)
    - Observe individual schools over short ranges
    - Quantify geometry inside of school
  - Mid-frequency multibeam sonar
    - Image large volume of water
    - Quantify gross school movement
    - Back and bistatic-scattering

- *Relate mid-frequency acoustic bistatic and back scattering to high-frequency multibeam and split-beam backscatter and both to fish activity*
  - Determine how fish distribution (school structure) is related to long-range acoustic scattering
  - Use traditional techniques with new methods to determine which fish are present, in what numbers, and how they are distributed
  - Determine how variability within a school affects acoustic scattering

- *Relate fish causing acoustic scattering to physical and biological oceanography*
  - Characterize environment for different fish schools using the New Jersey Shelf Observing System

- *Obtain time series data*
  - Diel patterns in distribution of fish
  - Changes with physical environment

WORK COMPLETED

Development of two new sonar systems has been completed. The third and final field effort for this project was conducted in May, 2008. During this field effort, sampling was conducted with echosounders, nets, profiling instruments, gliders, and PIMMS. Field sampling was centered in the northeast corner of Monterey Bay where substantial commercial fishing effort was focused. Numerous schools of fish, primarily sardines and anchovies, were observed in this area and were sampled with all the assets of the program.

During the 2007 field effort, sampling with echosounders, nets, and the PIMMS was guided by observatory data whenever it was available. Field sampling was centered at the shelf slope break close to the 200 m isobath. High resolution mapping of the biology was conducted in 2 regions. One region was centered around the Hudson River canyon. The second region was centered along a series of offshore canyons located offshore Maryland and Virginia south of Delaware Bay. Glider deployments were used to map the physical and biological variability in the Hudson canyon and the relative variability in the physical and biological variability was similar for the canyons in southern domain.

The first paper from this work is currently in review (Wisdom and Benoit-Bird) while 3 others are currently nearing completion for submission.

RESULTS

2008 Field Effort

Numerous small schools of fish and their habitat were measured in Monterey Bay using the echosounders, multibeam sonar, PIMMS, gliders, CTDs, and nets. An example of data collected with the 120 kHz echosounder is shown in Figure 1.
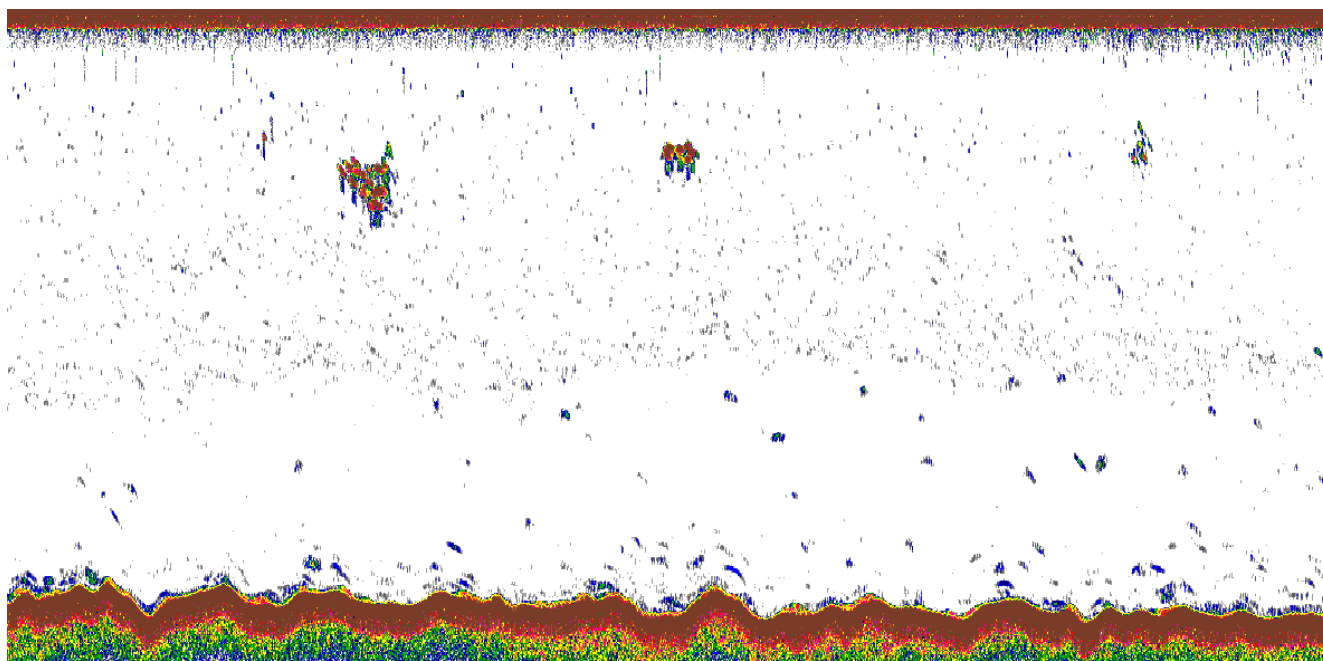

Figure 1. An example of fish schools imaged with the 120 kHz echosounder is shown. The total echogram is 250 m across and 20 m in depth. The backscattering intensity is shown in color with red representing strong scattering. Strong scattering from the seafloor is noticeable near the bottom of the echogram while strong scattering in the middle of the water column is from small schools of fish, likely sardines and anchovies.

These measurements provided the final example of targets necessary for verification of the performance of PIMMS and the new multibeam sonar.

As part of the 2008 field efforts, we also measured the amount of nocturnal light using light sensors developed during the 2007 field season. The development of these sensors is the subject of an in review manuscript by a graduate student involved with the project.
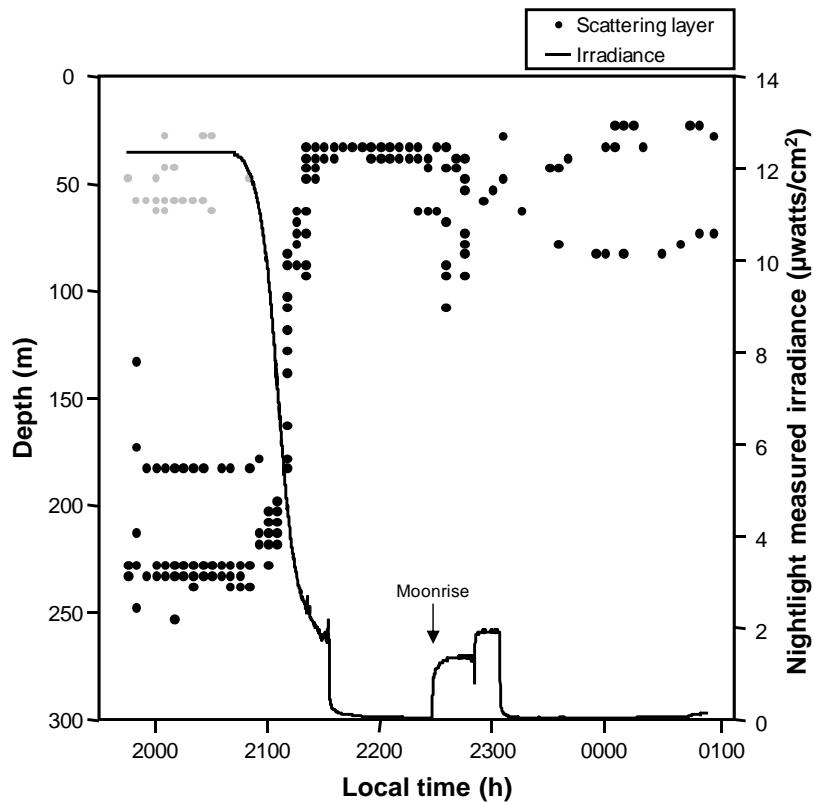
Figure 2. The depth of volume scattering layers detected with a 70 kHz split-beam echosounder (points) along with a plot on a log scale of light from a Nightlight (solid line) as a function of local time. The main scattering layers are indicated by the black points. A thin backscatter layer with a distinct frequency response that was not observed after sunset is indicated by light grey points. Note the inverse relationship of the scattering layer's depth and the light level available both after sunset and after moonrise.

2007 Field Effort

The 2007 field effort off the Hudson Canyon area revealed very low fish biomass. However, there were incredible patches of pelagic snails in the water column that were intense sources of acoustic scattering. These snails showed scattering as intense as dense schools of fish, suggesting their importance in the interpretation of acoustic data. We are currently completing a manuscript describing the scattering from these snail swarms.

Glider data was collected in the Hudson canyon during ship operations. Many of the patterns observed in the Hudson canyon were consistent with what was observed using ship-CTD sampling offshore Maryland and Virginia. The main feature present in the offshore waters was that water column was strongly stratified. Just below the thermocline there was a persistent subsurface chlorophyll a and optical backscatter maximum. There appeared to subsurface peaks in Colored Dissolved Organic Matter (CDOM) over the canyon. This was consistent with discrete pigment samples which indicated phytoplankton populations appeared to be dominated by picoplankton. HPLC analysis (still ongoing) indicates a significant presence of zeaxanthin which would be consistent populations of *Synechococcus*. Consistent with this observation was what appeared to be a phycoerythrin fluorescence.

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In both study regions, fish schools were small and relatively rare. Schools of fish in the more southerly site had horizontal scales of approximately 20-50 m, with vertical scales of 50-200 m. Repeated transects showed that the temporal persistence of schools in an area was less than 12 hours and was frequently less than one hour. However, in both study regions, zooplankton and micronekton were highly abundant with intense aggregations observed throughout the day at depths greater than 200 m and during the night from the surface to approximately 100 m. Net tows showed that the dominant species varied dramatically over short space and time scales with clear differences in species composition associated with offshore and onshore waters. A unique acoustic scattering source was identified during the experiment as dense, monotypic aggregations of a pelagic gastropod were located during a 2-day period. These aggregations were remarkablystrong scatterers at frequencies ranging from 38-200 kHz. Data interpretation for this unusual sound scattering source is ongoing.

During the second field experiment, the Pelagic Imaging Midwater Multibeam Sonar (PIMMS) was successfully deployed in two new configurations. In the first year the PIMMS system was deployed off the side of the ship with the sonar hanging below the ship. This type of deployment is rapid, but ship noise and motion was a major source of acoustic signal contamination. For the second year experiments, the system was modified and deployed from a fixed mooring, allowing the ship to move away form the sonar. In addition to reducing ship noise contamination, the moorings enabled a time series of data to be collected in a single location while the ship performed down-looking sonar surveys and net tows in an area centered on the mooring.

Preliminary data analysis indicates that the system performed as expected with reasonable horizontal waveguide imaging at ranges of up to 2 kilometer in radius. However, limited fish schools were encounters during the field exercise. The time series data taken with the PIMMS mooring will likely provide the best data for imaging, capturing changes that occurred in one location. Most aggregation activity was observed during the dawn and dusk. However, fish aggregations were encountered on at least one occasion. Figure 6 illustrates a typical example of what is believed to be fish schools imaged during one of the day-long mooring deployments. This analysis is however very preliminary.

In addition to the fish, significant midwater scattering layers where observed with the down-looking sonars and net tows. Although these layers scatter weakly at the acoustic frequency of the PIMMS system (10-12 kHz) and are therefore difficult to image, several experiments were performed with the PIMMS system to investigate imaging horizontal structure in these layers. The hypothesis is that at the frequencies of the PIMMS system, weak scattering from these layers may still reveal large-scale horizontal structure (on the order of 100s of meters) in the layers if observed over long ranges. If such structure can be extracted from the imagery, the mooring data will likely be the best data set to analyze because of the improved signal to noise ratios in the backscatter data. A time series of images is also better for extracting weak signals because changes from image to image can often reveal hidden coherent structure.

IMPACT/APPLICATIONS

The distribution of fish and the variability in their distribution has implications for fisheries, stock assessment, and operational acoustic techniques. This is particularly true in continental shelf regions where fish densities are high and their distribution is highly patchy. This work will provide basic information on the structure of fish aggregations, the effects of fish aggregations on both mid and high frequency acoustics, and the relationship between mid frequency acoustic scattering and more

traditional, relatively well-understood high frequency acoustic scattering. In addition, we will examine the correlation between fish, important biological sources of acoustic scattering, and environmental variability by utilizing the existing resources of the New Jersey Shelf Observing System (NJ SOS). An understanding of the relationship between fish and their habitat will provide the opportunity to make predictions about the distribution of fish aggregations at the scale of the study region and the distribution of fish within an individual aggregation. This will contribute to our efforts model scattering from biological sources. We expect this work will allow us to develop new acoustic techniques, that expand our understanding of the basic biology of fish, understand the relationship between fish aggregation characteristics and acoustic scattering at mid and high frequencies, relate more traditional high frequency techniques to more complex scattering at mid frequencies, and explore the potential of mid frequencies in both direct and waveguide scattering for application to fish.

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